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Review of intelligent building construction: A passive solar architecture approach

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ABSTRACT

Due to the increase in living standard and demand, energy conservation has become important in industrialized countries. In view of rational use of energy, the present paper reviews intelligent building construction with the aid of passive solar architecture approach, which makes use of specific building design principles and reduces the artificial energy requirements for achieving indoor thermal comfort. As a climate responsive architecture, building design criteria has been studied with the help of several parameters like geographic location and climatic conditions, building shape, orientation, selection of construction materials, building openings viz. windows, selection of suitable sunshades, etc. All the salient building design parameters are studied and important findings and recommendations are suggested as the outcome of the study. The study in turn is useful for various resource persons involved in the construction activities for designing energy efficient intelligent buildings.

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1. Introduction

Many of the methods for extracting energy from the environment are designed to respond only to the particular phenomenon, which concerns them and even to this phenomenon only when it exists in a degree favorable to energy extraction. Buildings, however, are inevitably subject to a very wide range of influences and must be designed to give a satisfactory performance over the whole range of variation of the many phenomena concerned and at the same time, to establish a balance between the often-conflicting demands of these phenomena. The very difficult problem of design which this situation poses is made yet more complex, since the other functional and economic requirements which the building must meet will very often lead to design solutions that are different to those which would best meet the energy needs and a balance has to be made in the final solution. If this were a new problem, the awaiting solution it would present a daunting prospect. Any viable solution would necessarily be regarded as a remarkable achievement. Sophisticated design achievements have been made with increased comfort conditioning inside the buildings.

Most building designers have been able to work ignoring the external conditions so far as the basic plan, shape and materials of the building are concerned [1]. The aspect of natural environment involved in a consideration of ambient energy and the design of buildings can be grouped into categories of heat, light, air and moisture movement. In buildings the environmental control installations must be considered in relation to the external conditions. The basic shape may be governed by considerations of lighting, air movement and heating. The materials of construction may be dictated by thermal, moisture and sound considerations. Decisions about the window involve all the factors identified. Thus, various building components that are directly exposed to the sun are walls, doors, windows, ventilators, roofs, etc. Window is

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one of the most important components for direct gain of the building. In any particular design the parameters which significantly alter the solar contribution to the total cooling and heating load inside the building are

- Type, area and orientation of fenestration.
- Wall area facing the sun and all other wall areas of the structure controlled by site orientation.
- Ratio of window/wall area to control the amount of admission of incident solar radiation to the interior.
- Provision for shading devices, either fixed or variable to avoid the enormous solar heat gains.

2. Beam radiation and building design criteria

Clearly the success of utilizing the solar radiation depends on the size and orientation of the windows and also the materials of construction and finishes in the room. The intensity of solar radiation varies not only throughout the year and with changing weather conditions, but peak levels also occur at different times of the year according to the aspect at a particular geographical location. Although several models are available for the estimation of solar radiation [2–4] choosing proper model for the particular purpose is of interest. Some of the important contributory work done in the field of radiation estimation reviewed are correlation model for estimating monthly average values of global solar radiation from ambient temperature data [5,6], empirical method for computing daily total solar radiation depending upon climatic data [7] and synthetic daily sequences of hourly radiation values on horizontal plane for a particular location with clearness index as input [8].

Heat gain is also a function of the surface area of building envelope exposed to sunlight and in turn this area depends on aspect ratio of the building. Although the guidelines have been specified for the optimal orientation of energy efficient buildings as mentioned in Indian Standards [9], IS: 7662 (Part-I) which suggest a method to calculate heat gain, and A Manual on Solar Passive Solar Architecture [10], which suggest orientation direction and aspect ratio values on maximum–minimum scale, there is necessity to know the duration of sunshine and hourly solar intensity value incident on the surface for practical evaluation. Based on incident beam radiation and sunshine hourly data, the software tool [11] has been developed for the energy gain estimation over the exposed surface areas of the building for a particular location and specific aspect ratio. The developed tool is useful for deciding the specific building orientation, aspect ratio of walls and analyzing the effect of heat gain on multistoried buildings.

3. Simulation and indoor temperature

Passive solar system is a better alternative approach for thermal comfort conditioning inside the buildings. Garg [12] determined the thermal environment in a traditional building envelope and by applying the recent passive solar techniques how far the discomfort can be controlled was examined. It was concluded that two-thirds of the discomfort could be eliminated by the judicious use of simple passive options based on thermophysical properties and configuration of building envelopes. Kumar et al. [13] introduced some of the passive cooling techniques like application of insulating material (coir fiber) and proper surface treatments. Raman et al. [14] developed passive solar system to provide comfort throughout the year in the composite climate. A passive solar chimney was constructed for heating, cooling and ventilation of the test-room. The amount of heat transmitted into or lost from a building varies with the change from day to night time temperatures and changes through fluctuating weather, i.e. heating by sunshine and cooling by wind or rain. The indoor temperature change depending on the amount of heat flux and broadly follow the pattern of outside temperature, although some displacement in time may occur between internal and external peak temperatures according to the thermal response of the building.

Simulation technique is a useful tool for the designers to achieve an optimum thermal performance of the localized buildings under given thermal climate [15]. Micro-site analyses in relation to thermal impacts on the building performance can be easily achieved by using physical modeling techniques [16]. In order to investigate the thermal simulation of a full-sized passive solar building using scale models, researchers constructed simplified single test-room and several test units of half and quarter-scale were used. Using thermal scaling technique, all the analyses of the test results suggested that it is quite feasible to simulate the thermal performance of full-scale passive buildings. Thus, one of the simple ways to simulate the thermal performance of the building is to consider one room passive solar house design. Physical thermal (mathematical) model of passive-solar building design was also derived [17] for the small-scale constructed models and thermal performance of the models was computer simulated using weather and solar radiation data. Simulation and experimental values was compared and found significantly equal [18]. Hay and Yellott [19] considered small passive-solar test box for building design. The steady-state thermal conductance of walls had been used to calculate a thermal load for a given temperature difference between building interior and ambient temperature. But for the validation of the model by the experimentation is important. Athienitis and Ramadan [20] developed an explicit finite difference simulation model to study the thermal behavior of a room under different control strategies for the shading device over transparently insulated south facade wall. The simulation approach helps to decide the overheating period and suitable option to use particular movable sunshade. All of the above mathematical approaches involve tedious calculations, which in turn increase computation time. The physical model can be simulated with the help of computer. There are two practical reasons for turning to computers as an aid in environmental design: they can save the designer effort and time and they can offer the opportunity to work with more complete information about the effects of design decisions. A Computer simulation analysis had been employed by Balcom [21] to aid in the selection of components whose results indicated that a performance comparable to that of a conventional active solar heating system should be achievable in an optimized design passive-solar heating system. Andre et al. [22] developed an evaluation methodology and monitoring plan for passive-solar commercial buildings. Together with the experimental investigation intensive computer simulation work had defined an optimized design of the building. Bansal et al. [23] extended the concept of solar gain factor and the overall heat loss coefficient to size the building elements for different climatic conditions. The developed SUNCODE software helps to determine only the room temperature for a specific wall. Schultz and Svendsen [24] developed a two-node model of a room and implemented in a computer program, WinSim, for the evaluation of thermal performance of windows in new buildings and in case of retrofitting. The computed values were compared with an advanced building simulation program. The compared results found slightly deviating with the reported cause as difference in time basis. Gupta and Ralegaonkar [25] developed a MATLAB software tool to determine the room temperature and found performing much similar as that of performed experimental results. Fang and Li [26] developed a three-dimensional transient heat transfer model of the lattice passive-solar heating wall using

Finite Difference Method and the simulation software was generated in FORTRAN. Nayak and Francis [27] developed integrated software, TADSIM for automatic linkage between design and simulation of thermal performance of buildings. The interface enables the user to carry out building simulation using commercially available software, namely TRANSYS (version 14.2) and DOE-2 (version 2.1 E).

4. Sunlit area

Energy conservation has been defined as the strategy of adjusting and optimizing energy using systems and procedures to reduce energy requirement per unit of output without affecting socio-economic development or causing disruption in life styles [28]. It has been reported by Qian [29] that the residential buildings should have at least two hours sunshine during the day in winter. Since then, many countries have set up their own regulations for sunshine hours of residential buildings, which show that the problem of residence sunshine has been attached increasing importance. There can be a significant impact on energy conservation by controlling and managing the energy systems in the buildings. Energy management can be done by determining optimum energy settings and policies for the control of the energy systems. The goal of energy management is to provide a comfortable environment in the most economical way possible. Passive-solar architecture aims at maximum living quality with minimum environmental impact, which in turn satisfies the goal of energy management inside the buildings. Direct gain system like unconditioned sunspaces provides extra surface for absorption of solar radiation and extra mass for its storage, is the most effective as far as heating and day lighting inside the passive-solar building is concern [30]. The principle involved for comfort conditioning of buildings is to regulate sunlit penetration through windows or building openings depending upon the seasonal requirements. The entry of sun directly into the room constitutes major about of the total heat inflow. Thus, although heat penetrates the interiors by convection (moving air), conduction (through walls) and radiation (by penetration of sunlight), radiation control is of great concern for comfort conditioning of buildings throughout the year [31]. Solar radiation is an important term in the energy balance of a building and one must account for it in the calculation of loads. Sunlit area is a measure to determine the radiation interception, which regulates temperature inside the buildings.

For analyzing the systems with solar gains, design tools should have a reliable and accurate means of predicting the solar radiation surfaces, which helps to calculate internal solar distribution for the building simulation [32]. Since solar radiation on a surface is often greatly influenced by self-associated facade obstructions, neighbor buildings and the surrounding landscape, a prerequisite of solar modeling is the ability to predict shaded and unshaded building parts as a function of solar position and geometry. Researchers introduced a simulation program called TRANSHD for external and internal insolation calculations of buildings. The discussion presented for the frequency at which beam radiation is performed yields the conclusion that the calculation on an average day of each month is sufficient. However generalization of the results is difficult due to parametric constraints like geographical location and weather data. Kreith and Kreider [33] presented the method for calculating the shaded portion through the opening depending upon the location. But the methodology for the calculation of shadow angle protractor is tedious and time consuming; as well as it gives some approximation in the calculation. To determine the shading at a particular instant of time; when the sighted object is distant as compared to the dimensions of the surface whose solar exposure is to be studied one can superimpose the outline of the horizon, on sun path diagram and can be said that the point is shaded when the sun path passes below this horizontal outline. But for cases such as an overhang above a window, mathematical formulae were presented [34]. The basic assumption made over here is shading devices are long enough and hence end effects can be neglected which is not the practical case where sun shade have finite dimension in all respect. Niewienda and Heidt [35] described a method for calculation of sunlit area both direct and diffuse, using set theory and implemented in the program SOMBRERO. The mathematical formulae presented in several approaches to determine sunlit area inside the buildings faced the problem of numerical approximation. Ralegaonkar and Gupta [36] presented a graphical solution for measuring the sunlight area thorough various building openings with the help of AUTOCAD 3D Modeling. Marion et al. [37] developed a computer program for shading and insolation calculations of the buildings. The program determines the sunlit area within the building. The program can handle a large variety of surface shapes as well as beam and diffuse radiation.

5. Sun shading

Energy efficient building design includes considerations for adequate lighting, improving thermal comfort and shading against excessive solar intrusion. The use of passive cooling and heating can significantly contribute in reducing the total energy consumption of the buildings. Windows which play important role for the heating as well as cooling of the building for passive solar design should be properly shaded to avoid overheating as well as energy saving. The shading devices for various facades of the building can be classified as interior and exterior devices. Kischkoweit-Lopin [38] studied various passive-solar system components like shading systems affecting daylighting inside the buildings. An overview of various existing sunshades has been presented with illustrating sketches and short detailed descriptions to choose the right system for a given condition. Sunshades are not only responsible for reducing the room temperature during hot season but are equally responsible to heat up the space inside the building during cold season. Some of the examples are illustrated for their relative performance as radiation filter.

Littlefair [39] discussed the ways to ensure solar access in obstructed situations, both within new developments and in existing buildings nearby. He gave the design guidelines for the both existing and new buildings for United Kingdom. Because of reduction in free space in adjacent buildings, free air circulation reduces, and there is an increase in heating and cooling loads. Therefore, there is a need for more effective shading devices on the walls especially in densely populated urban areas. To protect full glass window wall, which offers very little (around 12%) protection from radiation prismatic panes were developed [40], which are shading responsive to sun's position for different seasons throughout the year. The panes are suitable for windows or facade elements, preferably in applications, which do not need a clear view. Kassem et al. [41] developed the computational procedure for evaluating the solar heat gain to a space having a vertical cylindrical glass envelope, which can be made useful for proper selection of shading device. For the region over Middle East, with large areas of glazing in commercial buildings, triple-glazed window were proposed [42], which helps to reduce air conditioning demand. But the specific glass type may face problem of high initial and installation cost.

To protect the window man made shades like fully opaque curtains are retrofitted to the buildings. For the cooling of buildings Sodha and Bansal [43] considered roofs and windows as the important components. Researchers considered windows with movable screens for cooling effect. Givoni [44] studied the application of various passive-solar heating systems with main design factors affecting their performance. For solar control the researcher considered mechanically operable internal shading

devices for windows. Zaheeruddin [45] gave the design for automated window shutters. Researcher considered room temperature and solar flux as design parameters for the control of shutter closer or exposure. They were more effective than manually operable shutters. But the operational and maintenance cost vary significantly; as well they are not often recognized as architectural elements.

6. External static sunshades

The best method for radiation control is to apply proper external static sunshade. It intercepts the sun before it falls over the window on a particular wall facade and thus the method is sound and most suitable. They proved to have performance in most efficient manner as their geomerty can be designed as per changing seasonal sun path to achieve summer shading and winter heat gain. Location, latitude and orientation all contribute to the formulation of an effective device. The efficiency can easily be measured graphically by generating shading characteristics for a particular sunshade i.e. by plotting shading mask diagram [46]. The shading masks were plotted for several external sunshades [47]. The design procedure has been mentioned by Cowan [48] along with several case studies of external static sunshades of the buildings in Australia.

Ralegaonkar and co-worker [49] briefed the methodology for the performance evaluation of external static sunshades by the shading mask graphical approach under given location with the specific case study in India.

El-Refaie [50] studied the performance of the basic vertical and horizontal types of external shading devices. The different performance modes were presented in the form of shading masks featured by cutoff angles. He derived mathematical formulae to express the cutoff angles in terms of various geometrical parameters. The limited study has to be developed further for more complicated geometrical shapes.

A practical tool was designed by Jorge et al. [51] for sizing optimal shading devices. These approaches were applied to very basic types of sunshades like horizontal or vertical one. Researchers presented a nomogram for use in regions with a Mediterranean climate to optimize the design of shading devices. The nomogram allows the performance of a proposed external fixed shading device to be evaluated. But the graphical approach leads to an error of about 10%, which is quite significant.

Beam radiation, which penetrates inside the buildings through various openings, can be controlled using sunshades for the temperature regulation. Yener [52] presented a mathematical model for the design of fixed shading device from two aspects: climatic and visual. The study was restricted to horizontal and vertical shading devices only. Chandra [53] gave the design of external louvers/projections in relation to different building facades taking diurnal and seasonal variations of sun positions. The study was limited to basic types of external sunshades like horizontal, vertical, inclined and egg create. Parishwad et al. [54] discussed the various thermal considerations in the design of building components for the tropical regions in India. The entire zone has been classified into six climatic zones. Various techniques of passive cooling using insulating and reflecting materials in walls and roofs and developments in energy efficient windows were discussed in detail. Researchers considered only horizontal external shading on the south walls to protect sun entry from top.

Using Computer Aided Design Tools Kabre [55] had generated new possibilities in the passive solar design of buildings. WINSHADE is an integrated computer tool for the design of passive solar control through building fenestrations. It is based on the generation and the optimization paradigms of Computer Aided Design. Given the required inputs, it automatically generates prescriptive quantitative information to design optimum external shading devices and to select appropriate type of class. The models presented were tested with basic types of sunshades like horizontal and vertical one. Provision of suitable glass may obstruct low sun in peak winter period.

Dubois [56] presented a simple chart useful to design shading devices. The chart, which is complementary to existing solar path diagrams, provides additional information about the window's solar angle dependent properties and its geometrical relationship to the sunbeam. This information allows making meaningful hypotheses about the optimum geometry of the shading device. Two examples were provided where the chart is used to define the geometry of an awning on a south and west-oriented office room in Stockholm. The examples show that the chart is useful to restrict the early design hypotheses and identify the optimum awning geometry at an early design stage.

Ralegaonkar and Gupta [57] presented the new methodology for design of external static sunshade. The complex geometry has been constructed with the aid of Ferro-cement technique [58]. Several small scale models were analyzed to evaluate the performance of new static sunshade and also found efficient as compared to existing one [59,60].

7. Conclusions

From the literature review as discussed above, it is concluded that

1. For passive-solar architecture, the most significant design parameters which alter the solar contribution to the total cooling and heating load inside the building are aspect ratio of walls, orientation of the building, window details (size and location) and proper sun shade to control the amount of admission of incident solar radiation.
2. To meet the heating and cooling requirements, the selection of proper building orientation for a particular aspect ratio should be done with the computation of beam radiation falling over exposed wall surface.
3. Small scale modeling technique is one of the easy and best methods of experimentation to analyze the effectiveness of a particular system. For fast and accurate computation simulation software is the best suitable option to predict and control the indoor environment.
4. Sunlit area is a measure to determine the radiation interception, which regulates temperature inside the buildings. Graphical determination of sunlit area will be helpful for easy visualization and accurate measurement.
5. Windows, which play vital role for solar incursion inside the buildings, should be shaded properly to regulate the sun entry as per seasonal requirements in composite climates. External static sunshades are most efficient among all the types of sunshades as they restrict the sun before it interacts with building components (wall, window).
6. The existing external static sunshades (horizontal, vertical and egg create) satisfy shading needs partially. To check the effectiveness of a particular sunshade shading mask can be plotted.
7. The efficient external static sunshade should be designed as per the location constraint, which will follow sun path at a particular geographic location whose shading characteristics can be controlled as per seasonal requirements.

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